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REPORT NO. 15-90

UNDERWATER PERFORMANCE CHARACTERISTICS
OF EXPLOSIVE CUTTING TAPE

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Explosive Cutting Tape (ECT) is a flexible linear shape charge manufactured in five different explosive loads to cut various material thicknesses. ECT was tested on the surface and at 1, 33, 66, 99 and 132 FSW to determine underwater effects. Degradation of performance for the five sizes of ECT varied from 12.4% (average) at 1 FSW to 78% (average excluding 4700 gr/ft ECT) at 132 FSW compared to surface firings. 4700 gr/ft ECT performance was degraded only 47% at 132 FSW. Although ECT does suffer a performance loss in water, its capabilities at various depths can be reliably predicted. Explosive cutting tape efficiency, versatility and ease of use by divers make it an invaluable addition in the Navy's inventory. It is highly recommended that ECT be made available to the salvage community as soon as possible.

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I. INTRODUCTION

The Navy Experimental Diving Unit (NEDU) sinking of the ex-USS STRENGTH in 1987 provided the first look at a new explosive product, Explosive Cutting Tape (ECT). NAVSEA Task 88-08[1] directed NEDU to do follow-on research, evaluating commercial explosives and techniques for use by Navy salvors. The original success with ECT led to further testing with a goal of incorporation of this product into the Navy stock system for use by Special Warfare Units, EOD, and salvage divers.

Explosive cutting tape was originally manufactured by the Royal Ordnance Facility, Chorley, United Kingdom. Royal Ordnance has since granted manufacturing rights to a U.S. company, North American Explosives, Inc., Kentucky.

While the performance of ECT on the surface is well documented[2], very little work has been done to determine what effect water tamping, standoff reduction, and water intrusion in the standoff cavity has on ECT. Therefore, this study was designed to:

1. Evaluate various initiation methods for explosive cutting tape in an underwater environment.

2. Determine if placing ECT in 1 FSW, where there is no reduction in standoff from hydrostatic pressure, would degrade its performance.

3. Determine the amount of standoff reduction through hydrostatic pressure at various depths and corresponding performance changes.

4. Establish penetration and severance capabilities of ECT in steel at various depths of seawater.

5. Document if a single strand of detonating cord run from the surface to a main charge at depth would reliably propagate the explosive train.

II. FUNCTIONAL DESCRIPTION

ECT is designed as a flexible linear shaped charge consisting of an explosive charge of 88% RDX and 12% inert plasticizers, a flexible copper liner and a two piece expanded polyethylene foam housing (Figure 1). The housing serves to provide an integral stand-off resistant to filling by water but is compressible under pressure. The shaped charge liner is produced from a powdered copper mixed with plasticizers. ECT was provided for this study in five sizes, 300, 600, 1200, 2400 and 4700 grains per foot (gr/ft). The base of four of the five sizes of ECT each had an adhesive tape for mounting to the target. The 4700 gr/ft size was not equipped with this tape for unknown reasons.

Numerical Values:

Grams/Meter	Calculated Grains/Ft		Designation
63	296	->	300
125	588	->	600
250	1176	->	1200
500	2352	->	2400
1000	4704	->	4700

III. TEST PROCEDURES

A. TEST PERSONNEL

The personnel used to conduct this evaluation were all members of NEDU's Salvage Demolition Team. While their experience with explosive devices is varied, all received initial certification through first class diver training. All personnel involved in this test were also trained and certified as explosive handlers at NEDU. Numerous orientation shots were set and fired by each team member to ensure familiarity with ECT, charge orientation and initiation methods before actual test data was collected.

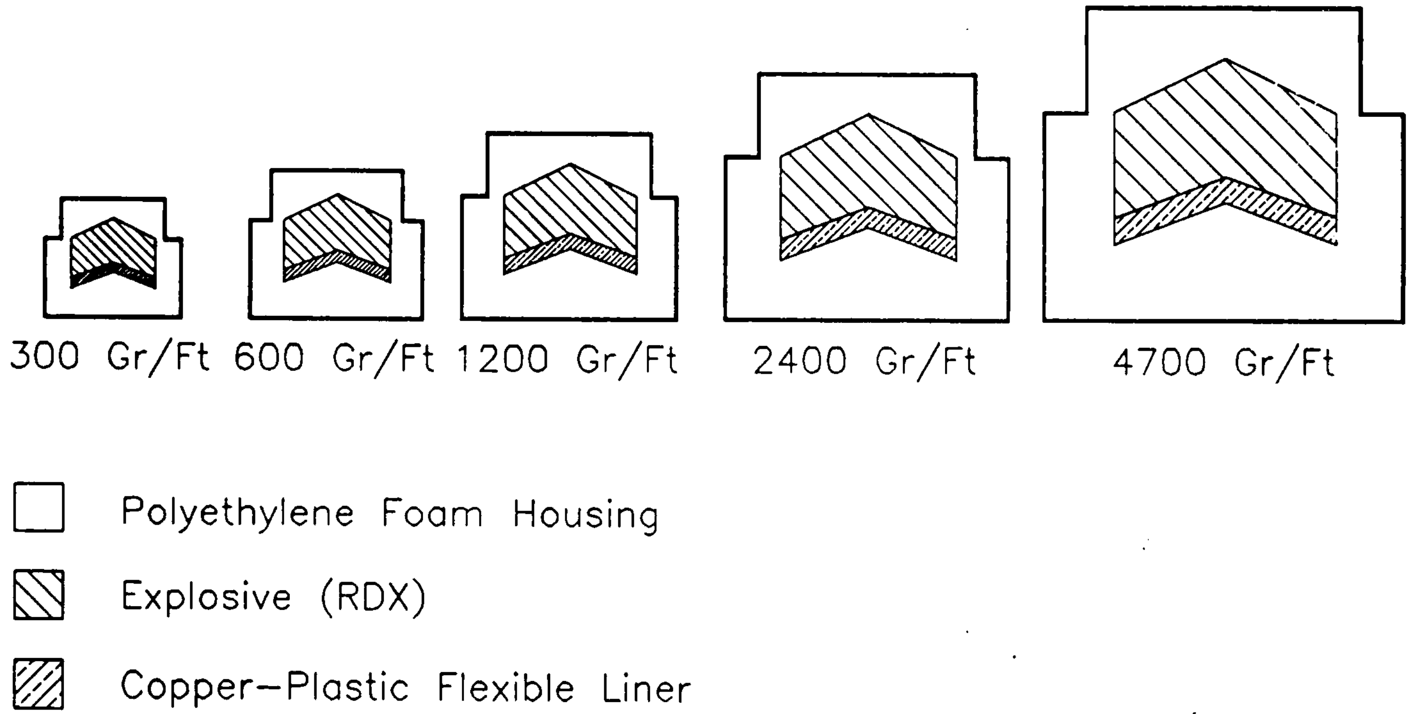


Figure 1. Explosive Cutting Tape (Cross Section)

B. WITNESS MATERIAL

All test samples were fired against witness plates of a mild structural steel (ASTM class A36). Data for A36 mild steel are: tensile strength 58,000 to 80,000 pounds per square inch (psi), yield strength 36,000 psi, and Rockwell hardness of 135. The plates were laid flat on a sand bottom for all firings. For the penetration tests, the witness plates used were a minimum of twice the thickness of average penetration. For severance studies witness plates from 1/8-inch to 3/4-inch were used.

C. MEASUREMENTS

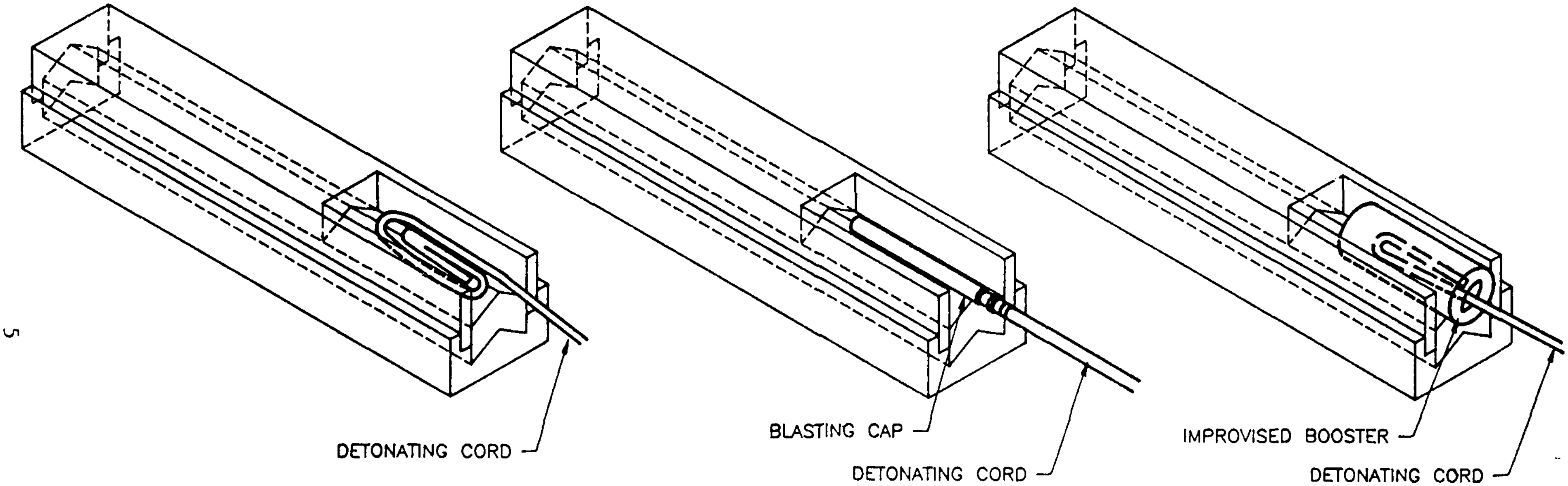
During the penetration tests, the depth of each cut in the witness plate was measured using a digital depth micrometer (Mitutoyo Inc., series 500) accurate to $\pm$ .001 inch. Depth measurements were taken at 1-inch increments over the length of the cut.

D. INITIATION METHODS

Three methods of initiation were evaluated during the surface and 1 FSW portions of the test. Each method is illustrated in Figure 2.

1. The first method of initiation tested was by using det cord only. Eight inches of 49 gr/ft detonating cord (NSN 1375-00-028-5166) was coiled to produce four 2-inch lengths. The foam padding was removed from the top of each ECT sample and the detonating cord was taped in direct contact with the ECT explosive as near the apex of the charge as possible.

2. The second method was through the use of sensitized detonating cord. A M7 non-electric blasting cap (NSN 1375-00-283-9440) was double crimped to the end of 49 gr/ft detonating cord and waterproofed with Aqua-Seal neoprene cement. The ECT foam housing was slit at the charge apex to accommodate the cap. The cap was placed lengthwise along the charge and taped in direct contact with the ECT explosive.



METHOD 1

METHOD 2

METHOD 3

INITIATION METHODS
FIGURE 2

3. The third method involved an improvised duplication of a commercially produced 20 gram booster. A 1-inch by 2-inch strip was cut from 22 ounce rolled data sheet (NSN 1375-01-036-0444). The bitter end of a piece of 49 gr/ft detonating cord was folded back on itself 3 inches and the data sheet strip was then tightly wrapped around this loop and taped with electricians tape (NSN 5970-00-816-6056). A "V" shaped groove was pressed in one side of the booster. This groove was designed to accommodate the apex of the ECT to insure direct contact between explosives.

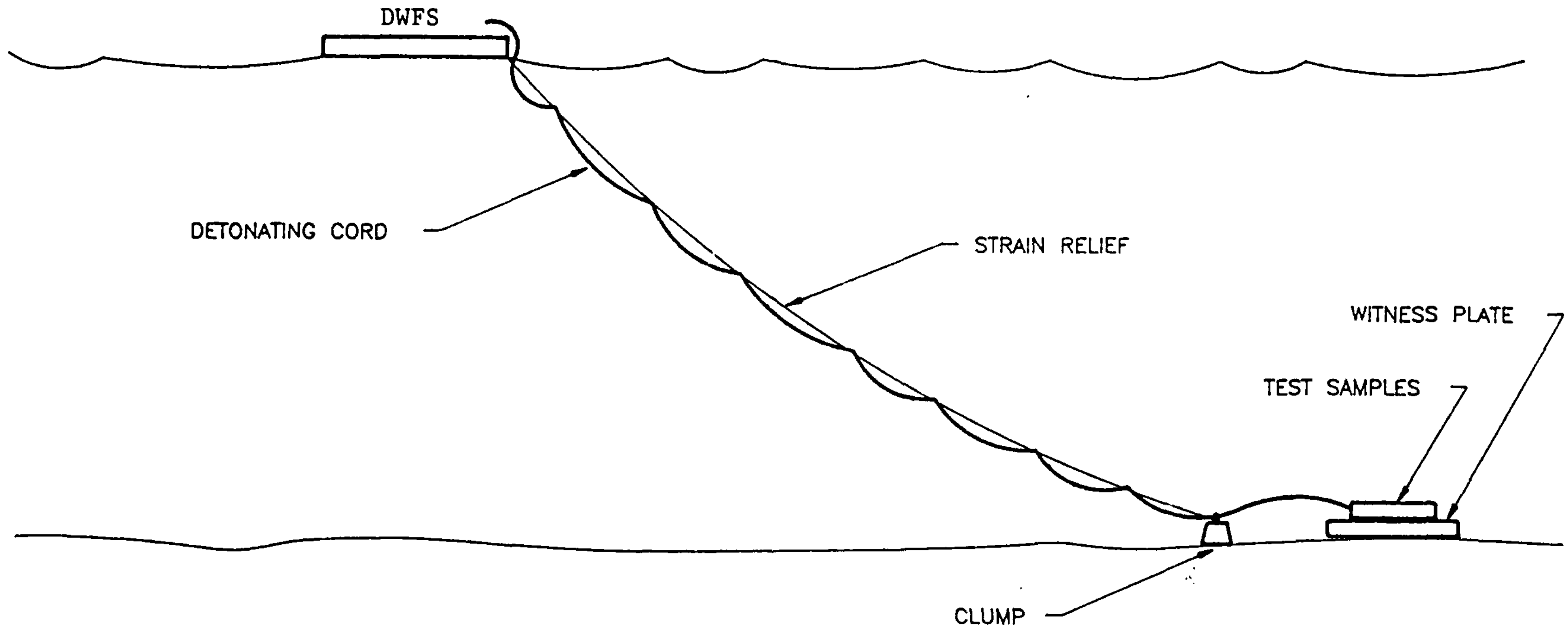
The det cord leads for each initiation method were cut to the same length from a single roll. This insured simultaneous detonation of each sample, preventing interference of shock waves on adjacent charges or witness plate. All leads were positioned with bitter ends flush and taped tc the detonating cord run to the initiating point on the surface.

E. EXPLOSIVE TRAIN RELIABILITY

Many units reported running dual strands of detonating cord from the surface to the main charge at depth to insure against kickouts. To determine the need for this duplicity, all shots fired during this study used only one strand of detonating cord run from the surface to determine if a single strand is reliable as an initiation system. A cross section of military det cords were used for the down runs to assess overall reliability. A dual non-electric waterproof firing system (DWFS)[3] was attached directly to the detonating cord down run. In addition, for the open water shots a light line was married to the detonating cord every 3 feet and secured to a clump placed on the bottom to act as a strain relief (Figure 3).

F. CHARGE PLACEMENT

Test shots were conducted on the surface and at 1, 33, 66, 99 and 132 feet of sea water (FSW). A minimum of three samples (6 inches long) of each size of ECT were tested at each depth. Figure 4 shows a typical test shot orientation. All charges were placed the same for both penetration and severance tests. The test samples were centered to avoid cutting from the edge of the witness plates. All charges were secured to the witness plate by wrapping the charge and plate with divers tape (NSN



NOTE: SCOPE OF DETONATING CORD SHOULD BE MINIMUM OF 2:1

TYPICAL EXPLOSIVE TRAIN COMPONENTS
FIGURE 3

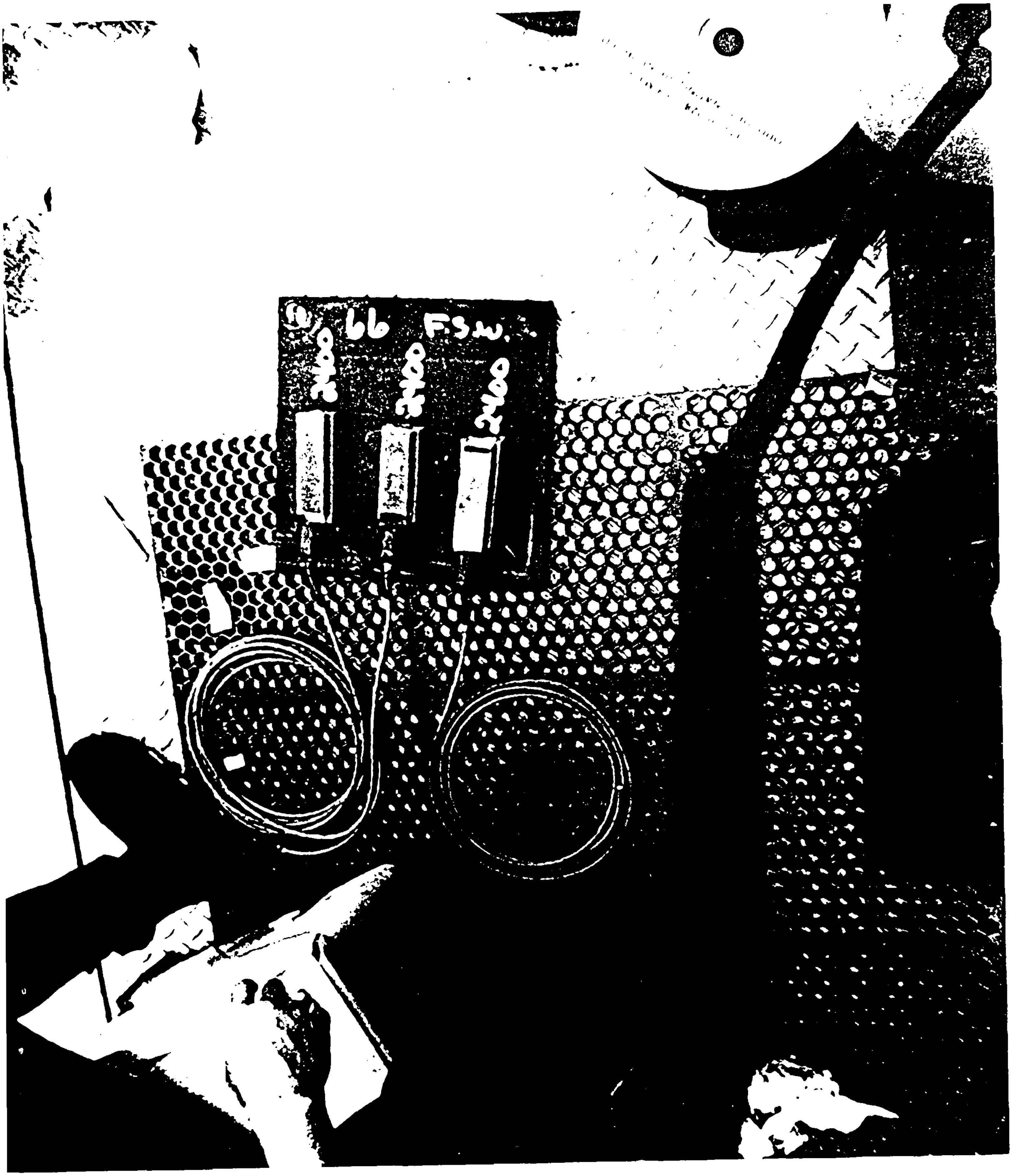


Figure 4. Typical Shot Orientation

4220-01-172-7574). The tape served to insure intimate contact over the entire length of the charge and to guarantee the charges stayed in place until they were initiated.

G. STANDOFF REDUCTION

It was known that the polyethylene foam housing on explosive cutting tape would compress under hydrostatic pressure. Assuming the reduction in standoff would degrade performance, measurements of standoff were taken using a dial caliper (No. 120 L.S. Starrett Co., Athol, Massachusetts) on the surface and at depths to 132 FSW for comparison to charge performance data at corresponding depths.

IV. RESULTS

A. INITIATION METHODS

The outcome of the tests to determine a reliable initiation for ECT are shown in Table 1. The number (N) reflects the total number of test sample firings attempted and includes all ECT sizes.

Table 1

Initiation Method Reliability

Initiation Method	Full Rate Detonation	Low Order or Failure to Detonate	Success Percentage
Detonating Cord Coil (N = 32)	12	20	37%
Sensitized Det Cord (N = 28)	18	10	64%
Improvised Booster (N = 115)	115	0	100%

B. EXPLOSIVE TRAIN RELIABILITY

During this study 27 shots were fired at various depths from 33 to 132 FSW. On 26 of 27 of the shots the explosive train was successfully propagated from initiation point to main charge. The one failure was attributable to a kink in the reinforced detonating cord (NSN 1375-00-310-2678) detected but not corrected as divers returned to the surface.

C. STANDOFF REDUCTION

Compression of the built in standoff distance was measured from the surface to 132 FSW at 10 FSW increments. It was hoped to develop a direct correlation between reduction in stand off and ECT performance. The results of the stand off compression measurements are reported in Table 2 and comparatively shown in Figure 5. Stand off measurements were taken from the base of the tape to the bottom of the charge leg. It should be noted that underwater measurements made by the divers were as accurate as possible but some variation was expected and tolerated.

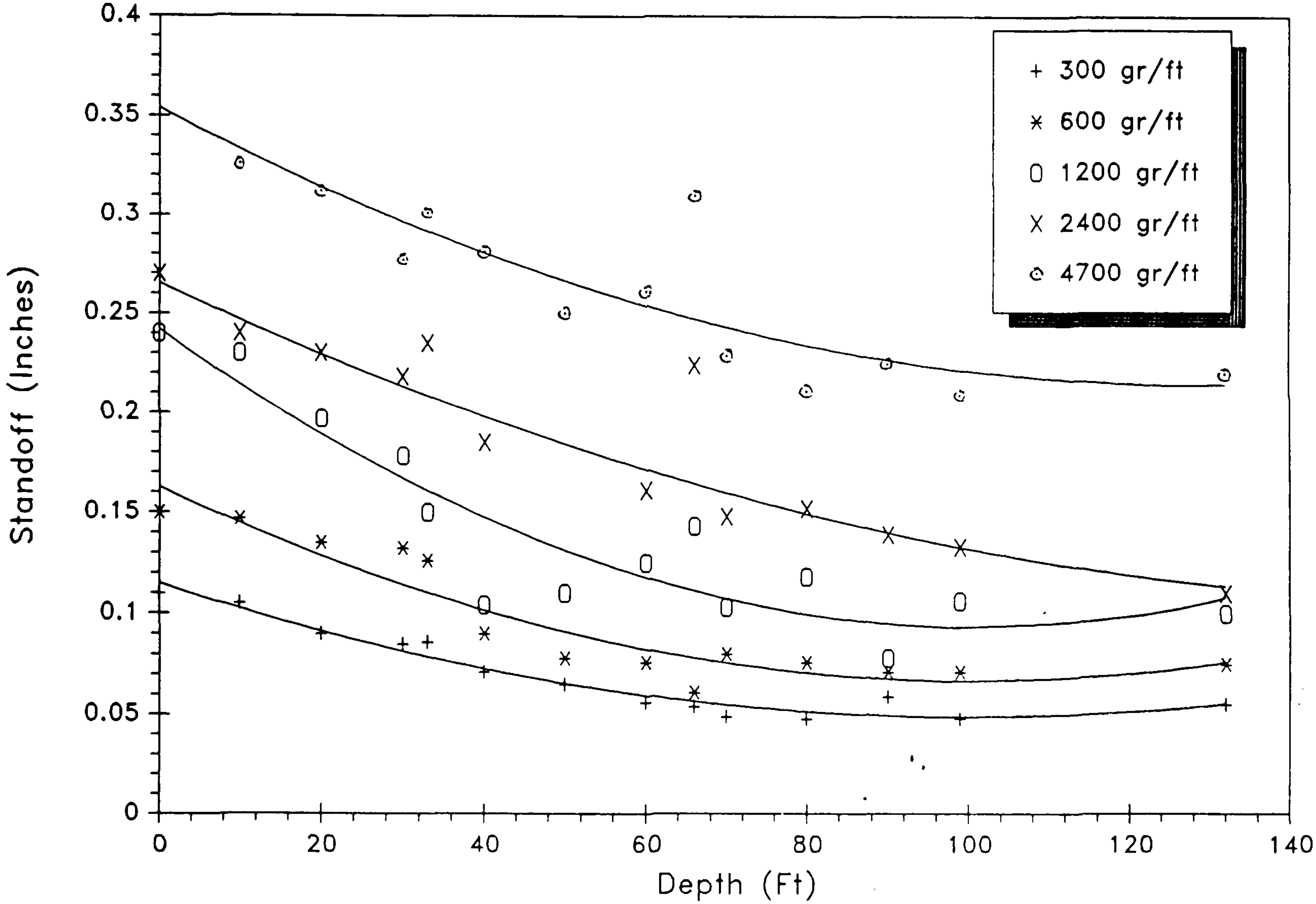
Table 2

Measured Standoff Reduction Data

(All Measurements in Inches)

Depth	300 gr/ft	600 gr/ft	1200 gr/ft	2400 gr/ft	4700 gr/ft
0	.110	.150	.240	.270	.363
10	.105	.147	.230	.240	.326
20	.090	.135	.197	.230	.312
30	.085	.132	.178	.218	.277
33	.086	.126	.150	.235	.301
40	.071	.090	.104	.185	.281
50	.065	.078	.110	.129	.250
60	.056	.076	.125	.161	.261
66	.054	.061	.143	.224	.310
70	.049	.080	.103	.148	.229
80	.048	.076	.118	.152	.211
90	.059	.071	.078	.139	.225
99	.048	.071	.106	.133	.209
132	.055	.075	.100	.110	.220

BUILT-IN STANDOFF REDUCTION BY DEPTH
Figure 5



D. PENETRATION STUDIES

The penetration capabilities of each size of ECT into A36 mild structural steel is presented below. The initiation charges placed over the ECT degraded performance directly below it. Therefore, penetration depth readings started after the point of initiation and measured in 1-inch increments respectively through the end of the ECT test sample. Tables 3 through 8 show the penetration data at 0, 1, 33, 66, 99 and 132 FSW without regard to the initiation degraded performance mentioned above. Figure 6 provides a graphic presentation of penetration capabilities at test depths.

Table 3

Surface Penetration Data

ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.114 (± .006)	.106	.129
600	.219 (± .011)	.194	.238
1200	.340 (± .026)	.296	.391
2400	.507 (± .039)	.500	.514
4700	.681 (± .041)	.549	.794

Table 4

1 FSW Penetration Data

ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.098 (± .010)	.083	.116
600	.192 (± .013)	.165	.215
1200	.333 (± .026)	.307	.398
2400	.445 (± .014)	.414	.472
4700	.511 (± .042)	.450	.574

Table 5

33 FSW Penetration Data

ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.093 (± .156)	.690	.127
600	.085 (± .037)	.800	.900
1200	.157 (± .024)	.115	.199
2400	.296 (± .018)	.280	.325
4700	.444 (± .030)	.402	.498

Table 6

66 FSW Penetration Data

ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.048 (± .010)	.0310	.055
600	.087 (± .012)	.065	.099
1200	.080 (± .002)	.077	.084
2400	.167 (± .043)	.160	.172
4700	.390 (± .046)	.185	.312

Table 7

99 FSW Penetration Data

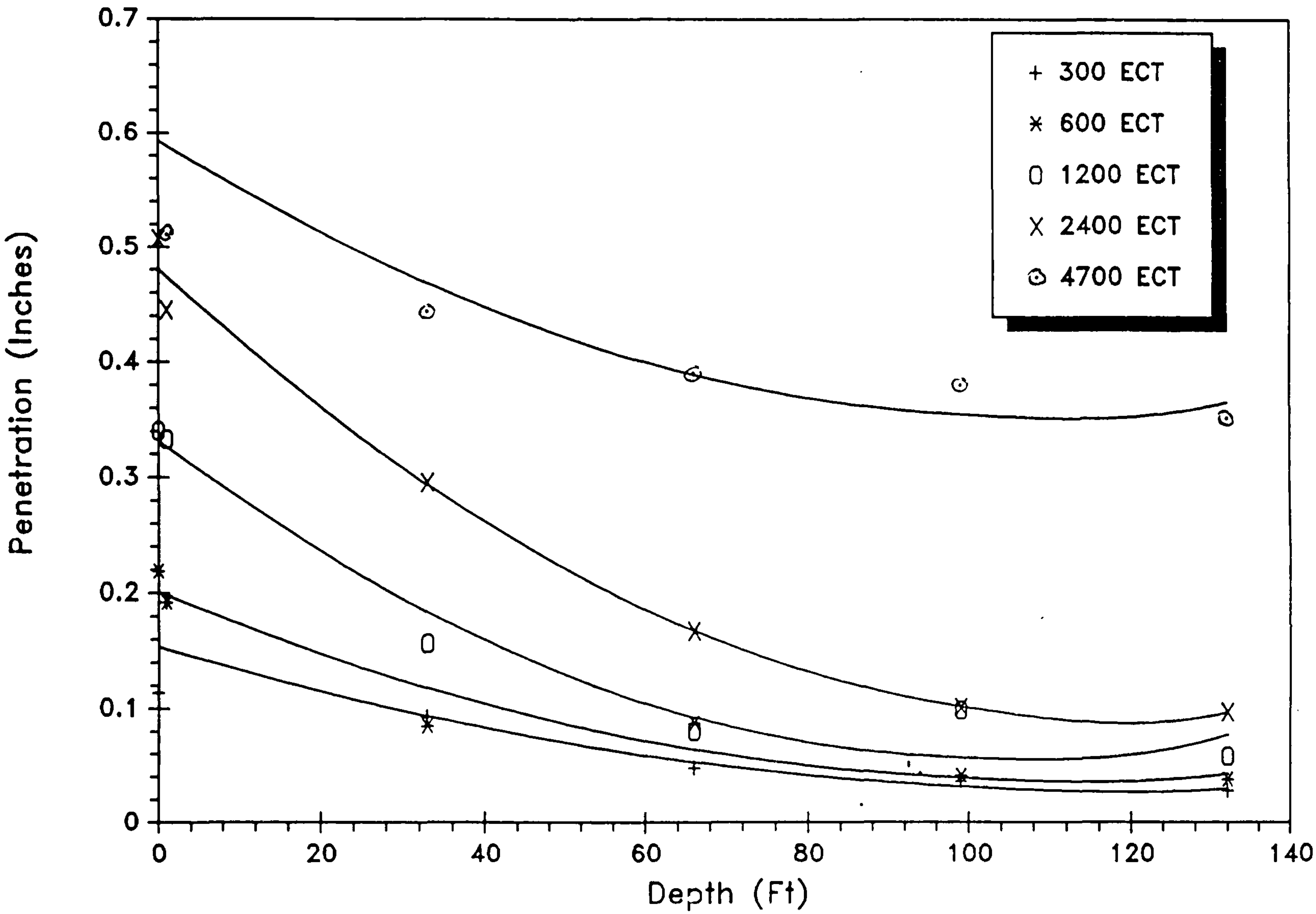
ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.036 (± .003)	.029	.040
600	.041 (± .007)	.030	.053
1200	.099 (± .004)	.094	.105
2400	.101 (± .003)	.097	.105
4700	.380 (± .021)	.361	.411

Table 8

132 FSW Penetration Data

ECT Size (gr/ft)	Average Penetration (inches) (± S.D.)	Minimum Penetration (inches)	Maximum Penetration (inches)
300	.028 (± .002)	.025	.030
600	.038 (± .002)	.035	.042
1200	.058 (± .005)	.052	.068
2400	.097 (± .009)	.085	.111
4700	.352 (± .040)	.292	.394

PENETRATION CAPABILITY vs DEPTH
Figure 6



E. SEVERANCE STUDIES

This portion of the study served to determine the maximum thickness of witness material reliably severed by each size of ECT at increasing depths. This test was only conducted at 33 and 66 FSW due to a limitation of resources. The results of the severance studies are shown in Tables 9 and 10. The first number represents the number of test samples which severed the plate. The second number represents the total number of samples fired.

Table 9

Severance Performance 33 FSW

ECT Size (gr/ft)	1/8 inch	1/4 inch	3/8 inch	1/2 inch	Reliable Severance
300	3/3	0/3			1/8 inch
600	3/3	0/3	0/3		1/8 inch
1200		2/3	0/3		1/4 inch
2400		3/3	3/3	0/3	3/8 inch
4700			3/3	4/6	1/2 inch

Table 10

Severance Performance 66 FSW

ECT Size (gr/ft)	1/8 inch	1/4 inch	3/8 inch	1/2 inch	Reliable Severance
300	0/3				< 1/8 inch
600	2/3	0/3			1/8 inch
1200	3/3	0/3			1/8 inch
2400		4/6	0/3		1/4 inch
4700		3/3	2/3	1/3	3/8 inch

V. DISCUSSION

Several fleet units were surveyed before the start of this test and all reported a standard operating procedure of a surface initiating charge and detonating cord run down to the main charge. Thus, a reliable method of initiating ECT from det cord was sought. As anticipated, the 8 inches of 42 grain det cord failed to reliably initiate ECT. This configuration places an insufficient amount of explosive (approximately 3 to 4 grams of PETN) in contact with the ECT main charge for consistent initiation. Using detonating cord sensitized with a non electric blasting cap also failed to consistently initiate the various sizes of ECT and this method is also deemed unreliable. The third method, an improvised 20 gram booster, achieved initiation on all shots attempted and is considered the most reliable method tested for underwater initiation of ECT using detonating cord lead.

The double backed tape provided as an integral part of the ECT appears inadequate to hold the charges in place during most underwater applications. The paper used to protect the tapes adhesive was extremely brittle and tore at every crease during removal. This made charge placement a tedious and time consuming task. Divers tape was used during this study to hold the charges in intimate contact with witness plates and prevent dislodging due to the large number of det cord leads running to each set of samples.

Any variance in the standoff (i.e. sea growth, bent metal, etc.) will have an effect on performance. A heavier explosive load should be considered when intimate contact with the target cannot be maintained.

While penetration capability of the various sizes of ECT is consistent and predictable, the severance capability is the opposite. The numerous factors involved in severance of steel (i.e. the medium on each side of the target, rigidity of target mounting, inherent hardness of the target, etc.) make reliable predictions extremely difficult. Through this and other tests at NEDU, it has been seen that as a general rule of thumb the mild steel severance capability of ECT at a given depth is approximately 1.66 times the penetration capability at that depth. For example, if a charge penetrates .60 inches it will normally sever 1.00 inch.

VI. CONCLUSIONS

1. All sizes of ECT display a degradation of penetration performance at depth. Based on ECT performance in surface tests this degradation ranges from an average of 12.4% by simply placing ECT in 1 FSW (with no appreciable standoff reduction due to compression of foam standoff) to an average of 78% at 132 FSW. The one exception was the 4800 gr/ft ECT which showed a performance loss of only 47% at 132 FSW.

2. The foam housing of ECT does not compress symmetrically. This makes shot orientation and placement difficult at depths greater than 50 feet.

3. ECT performance underwater is directly related to standoff distance which varies with depth due to foam compression. Assuming proper charge positioning, by determining the standoff at any given depth, the performance of each size of ECT can be accurately predicted for that depth.

4. The adhesive strip attached to ECT is not sufficient to hold charges in place in the majority of underwater applications.

5. A 20 gram booster of PETN data sheet reliably initiates all sizes of ECT on the surface and at depths from 1 to 132 FSW.

6. A single strand of any military det cord is sufficient to propagate an explosive train from a surface initiating point to a main charge at depths to 132 FSW (5 ATA).

VII. RECOMMENDATIONS

1. Through ship sectioning exercises and other evaluations at NEDU, explosive cutting tape has proven itself to be an extremely versatile tool with numerous applications. It is most strongly recommended that ECT be added to the salvage Navy's explosive inventory.

2. Due to the diverse requirements in salvage scenarios, all sizes of ECT should be available for use by the salvage Navy. However, 2400 and 4700 gr/ft sizes will find more application in an underwater environment and should form the bulk of acquisition.

3. Capabilities, applications and techniques for use of explosive cutting tape should be included in the curriculum for the salvage-construction diver/demolition technician curriculum (NEC 5375) once ECT becomes available to the fleet. In addition data from this evaluation should be included in the next revision to SWO61-AA-MMA-010, Technical Manual for Use of Explosives in Underwater Salvage.

4. There are several factors that influence underwater cutting with explosives which may or may not be discernible to the salvor. While highly conservative, the penetration depth vice severance values in this report should be used when planning cutting operations with ECT where a single shot, complete cut is required.

5. Alternate charge attachment methods should be evaluated for effectiveness.

6. A prototype of a more optimized 5400 gr/ft ECT has been produced and should be evaluated when available.

7. Commercial availability of proven reliably safe initiators should be examined as an alternative primary source of initiation in underwater explosive applications.

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3. Technical Manual for Use of Explosives in Underwater Salvage, NAVSEA SW061-AA-MMA-010 (formerly OP 2081), 1 March 1987.